Modular Modelisation and Simulation of the Instrument

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Abstract. Musical synthesis by physical model uses instrumental model simulation processes. In this paper we shall be discussing questions relative to the modular specification and construction of such simulations while allowing for the constraints linked to their execution in real time and the interaction between the instrumentalist. In the system we present the models are constructed by assembling mechanical components. Over and above these basic principles, specification modes for more macroscopic objects have been introduced that enable, depending on the case, better compromises between model complexity, variability, and simulation quality. These different functions notably make use of the instruments general specificities .

Introduction

Within a research framework that aims at understanding computer science as a musical creation tool, we shall consider the computer as a means of representing an "instrumental universe" with all its communicational attributes and properties. In this way, the computer *simulates* the physical object that the musical instrument is to such an extent, that the instrumentalist can establish a complete (gestual, acoustic, visual) sense relation with it.
Apart from this *instrumental playing* activity, the musician may choose to modify or to build the instrument object, and to use information tools to describe it and to produce the code for its simulation. The limits to and structuration of the field of instrumental objects that are thus representable is based on an initial option which is the use of models from physical mechanics as a simulation process reference. A second option is the *modularity* principle which implies that the instrument is buildable from the assembly of constituent parts, and that the latter are themselves simulable and experimentable as elementary instruments.
Blending model modularity with experimentability is a technical constraint, for it sets the triple problem of the language and tools to describe the object to be simulated, deriving an algorithm from its description automatically, and finally the optimality of the algorithm produced which must allow real time simulation.

The Basic system. Microscopic Modularity.

An initial system based on an atomic, (and consequently very general), description of mechanical objects was achieved in 1979 [1]. This first approach considered the mechanical materiality of objects in an overall manner before focussing the analysis on special instruments or on the latter's very specific properties.

Modular Modelisation

The mechanical object is thus represented by a network whose nodes represent the punctual masses. Arcs are the elements creating interactions between these masses. The representation system is therefore defined from a base of composable elements. The physical properties of the composed object originate from the properties associated to the base elements and to the laws of assembly. These properties come from elementary mechanics.

1) A position and an "external" force are associated to each mass. These are variables defined in a "displacement area", that is a priori 3 dimensional (normed R3), but that can be more restricted. These two variables are linked by the classical relation characterising the mass : F=mx"

2) Each liaison element has two extremities that may be defined as force-position pairs defined in the same displacement area: (x1,f1) and (x2,f2). The liaison element, under the principles of action/reaction and of behaviour invariance by space translation are then characterised by a formal relation type f1=-f2=F(x1-x2,x1'-x2')

3) When two masses are assembled by liaison, we merely have identification of extremity position variables to the mass positions. In a complementary way, the external force of each mass is the (resulting) sum of the forces associated to the liaison extremities connected to this mass.
A composite object is thus described by a list of components characterised by mechanical parameters and a connection plan. In practice, the connection plan is contained in the specification of the liaison elements of which the indexes of the masses that they link up appear as parameters.

Algorithm, algorithmic modularity.
The simulation algorithm is constructed in an immediate way : each component is associated to an algorithmic module and these modules interconnect according to the object's assembly plan. The mass elements are processed by modules that receive on input the liaison force they are connected to, and produce a position.

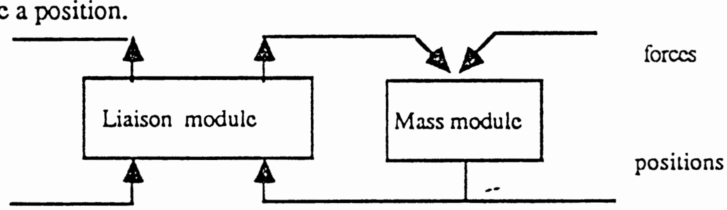
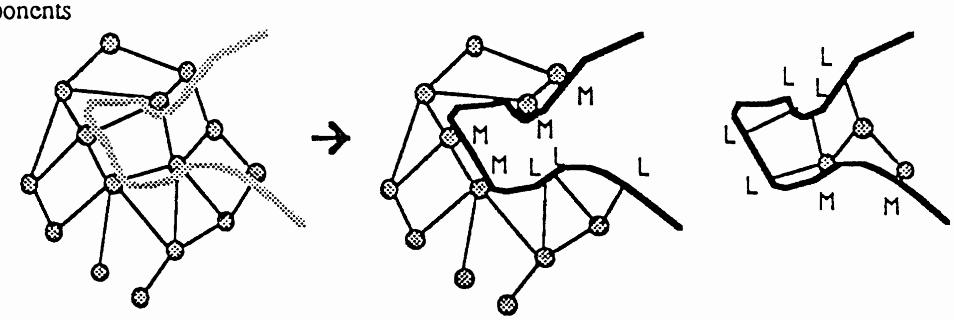


fig. 1

The liaison modules receive on input the positions resulting from these two mass modules that they link up, and produce two forces destined for these two modules.
The identity between model and algorithmic structures, that we refer to as *algorithmic modularity*, gives great variability to the simulated objects. Compilation processing only applies to the connection of precompiled modules. In the same way, dynamic parameter or structure modifications are possible without awkward extra processing.
Morerover, algorithmic modularity enables us to introduce new modules that are directly defined in algorithmic form and which fall outside strict physical description.
Atomicity can be unwieldy for describing complex objects and limits the performance of the algorithms, that are themselves atomised. With vibrating structures, where a large number of masses interact, this atomisation introduces distorsions into vibratory behaviour compared to the continuous time model (with localised masses or not).

Macroscopic Modularity

Our optimisation principles have been drawn from subsequent realisations that, on the contrary, stress the quality of instrument simulation in real time to the detriment of modularity [4]. Amongst other things, these principles make use of the functional specificities of instruments.
To be able to make full use of the above in a modular context, we have introduced a connexion principle that allows us to manipulate and assemble more macroscopic algorithmic components into a network and to do this independently from their construction mode which can then appeal to specific tools [5]. Objects are linked via the connexion points that they are intrinsically provided with. These points are in 2 categories, L points, and M points. By considering a composite object according to an atomic mass/liaison network type plan, we can "mesh" it into connected components



The borders thus defined cut through the arcs (the liaison elements) in the neighbourhood of one of their extremities, i.e. near a mass. What we designate as an L point is the interconnection point created on the constituent part that contains the liaison element.

This rupture brings out one of the nodes of the initial network as a complementary coupling point. We refer to this second category as an M point. This definition gives rise to several properties:

1) Liaison may only be established between two points of different types.

2) An L point may only be linked to one M point. In contrast, an M point can be linked to different L points, so therefore M points mask L points by connexion.

3) An M point connexion produces a position and receives a set of force inputs from the L points it is connected to. The L point receives a position input and produces a force.

4) All connexion topology data is associated to L points.

Although this is defined from the preceding modelisation system, this connexion principle is general and induces no constraint on the internal structure of the components. In this way, an M point is not necessarily associated with the simulation process of a mass element.

We should also point out that total compatibility with the first system enables the user to integrate objects constructed on an atomic level into libraries. The algorithm associated with such objects can remain atomised or, on the contrary, if the object is to acquire a high degree of permanency, it can be optimised by specific means external to the system. In this way, depending on the case, we can choose the best balance between the variability of the object and the optimality of its simulation.

Application to instrument modelisation.

Sub-systems to enable a specific description mode and algorithms can be used provided the constituent that is so produced respects the connexion rules in integrating itself with the other parts of the instrument. ,In this way the major constituent parts of the instrument, i.e. the vibrating structure and the exciter mechanism can be described, compiled and simulated in an adequate and specific manner.

The vibrating structure : modal synthesis

The vibrating structures of physical instruments correspond to the homogeneous elastic solid model. Representing them in network form may require a large number of identical masses, so we then concentrated on tools suitable for easy construction of objects presenting characteristics of homogeneity and multiplicity. One of the current means used is modal synthesis which notably avoids the inconvenience of algorithmic modularity applied to highly atomised structures [4] [6]. The modal model described in processing module form appears as a set of mass/spring/friction cells, coupled to connexion points via transformation modules operating on the input forces and the output positions. The connexion points are therefore M points. The object can be constructed in different ways:

- directly by specification of the modal parameters ; frequency, damping, and coupling parameters characterising the transformation modules.

- by specifying a physical model in the form of a mass-spring-friction network. In this instance the modal model is produced from the elasticity matrix by a diagonalisation algorithm.

- by the composition of the networks themselves defined by a modal model. This method is applied to structures presenting similarities that authorise certain kinds of coupling. For example, this method enables construction of "complex" structures from the coupling of identical elementary structures as strings.

The Exciter Mechanism

The mechanism that enables the vibrating structure to be excited by gestual action is fundamentally non-linear. To simplify, we can break down the mechanical structure/vibrating structure chain into two parts. One carries what we refer to as the exciter mass and a liaison element coupling this mass to the vibrating structure, and the other comprises an exciter mass drive mechanism derived from the gesture. The non-linearity of the EM/VS liaison is closely linked to the excitation mode, percussion, sustained oscillation , etc... Its influence on the characteristics of the acoustic signal in the very short term (the spectrum envelope) is considerable. The non-linearities present in the gesture/ exciter mass chain directly influence the reaction to the exciter gesture, and in a correlated way, the longer term characteristics of the acoustic signal. Two representation and simulation modes can be used for the exciter.

1) Spatial Modelisation

A number of non-linear physical behaviour types originate from geometric properties in a tridimensional displacement area. For example, the isotropy of interactions, the necessary occupation zone around any material point, induce non-linear behaviour as soon a displacements are substantial.

These properties can be integrated into an initial modelisation form. The objects evolve in a bi- or tri- dimensional space and are provided with interaction contours. Such a system, when used otherwise for image synthesis enables most of the gesture / vibrating structure chain non-linear mechanical functions to be modelised [7]. A certain number of L unidimensional points enables the exciter simulation process to be connected to the vibrating structure. These L points are associated with spatial images of the vibrating structure defined in the simulation field of the exciter objects. This system has been used to represent scenes of simple objects comprising a variety of bodies vibrated and excited by percussion. Representing instrumental functions in all their finesse within the framework of spatial modelisation is however very costly and this method is therefore more adequate for processing the gesture/ exciter mass chain, than that of the vibrating structure/ exciter mass chain.

2) "Topological" Modelisation

The system presented in the first part enables us to represent the dynamic functions of the components and of assembly. The displacement area is uni-dimensional and no space exclusion principle induces "implicit" non-linearities. Non-linearities are modeled via the *conditional liaison* elements. The conditional liaison associates a logical automat to a visco-elastic linear liaison that acts on its parameters or directly on certain variables. The automat is commanded from tests effected on the module inputs. The conditional liaison system enables us to model a large variety of non-linear behaviour types, by using the commutation principle between different linear behaviour states. The system has been completed by the definition of liaison modules based on continuous non linear interaction functions of the F(Dx) or F(Dv) type that respectively characterise non-linear elastic or viscuous behaviour. For example the non-linear characteristics intervening in sustained oscillation instruments can be finely represented and adjusted [8].

By definition this second form is totally compatible with the L.M. connexion principle.

Conclusion

We have presented two stages in the evolution of a modular physical model synthesis system. the first consists in setting the basis of a general modelisation language that is adapted to simulation. At the second stage, this language becomes specialised and enables a certain representation economy given the specificities of the instrument and its constituents. Despite a present distinct lack of calculating power for rich real time simulations, the tool we have built following the principles described enables pertinent investigation into uncharted instrumental territory.

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